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A PHYSICAL MECHANISM FOR THE PREDICTION OF THE SUNSPOT NUMBER DURING SOLAR CYCLE 21

By

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L. Svalgaard and J.M. Wilcox

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Abstract

On physical grounds it is suggested that the sun's polar field strength near a solar minimum is closely related to the following cycle's solar activity. Four methods of estimating the sun's polar magnetic field strength near solar minimum are employed to provide an estimate of cycle 21's yearly mean sunspot number at solar maximum of 140 ± 20. We think of this estimate as a first order attempt to predict the cycle's activity using one parameter of physical importance.

A PHYSICAL MECHANISM FOR THE PREDICTION OF
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Introduction

A variety of methods have been used by many scientists to predict
solar activity (Sargent, 1978). Often they rely on time series analyses
which assume implicitly that the solar dynamo has basic periodicities.
These methods are questionable in that the basic periodicities, if any
exist other than the 11-year cycle, can not be determined with the current
uncertain set of sunspot numbers (Mayaud, 1977).

Other methods, such as that of Ohl (1976), are based upon some
apparent precursor of sunspot number which the author has noted fits
past solar cycles. These methods will work if there is some underlying,
but as yet obscure, physical connection between the two. The method may
not work, or will break down some time in the future, if it depends only
upon the researcher's ability to notice an apparent high statistical
but not necessarily physical correlation.

We would like to discuss a method based upon the physical grounds
of our understanding of the solar dynamo process. One aspect which is central
to the solar activity cycle is that the magnetic flux from sunspots in a given
cycle cancels the existing polar magnetic flux causing the polar fields to
reverse (Babcock, 1961; Leighton, 1969; Parker, 1977 and Howard, 1977). Further-
more, it is the polar flux, wound by differential rotation into a subsurface
toroidal flux, which emerges as the next cycle's sunspots. Thus, on physical
grounds, we believe the strength of the sun's polar magnetic field at
minimum is related to the next cycle's sunspot activity. In this paper we
test this hypothesis by several graphs which are basically a plot of the
polar field strength, measured at solar minimum in various ways, versus

the next cycle's maximum sunspot number, as determined during the past
several sunspot cycles. We then use these graphs with our estimate of the
polar field strength during the present sunspot minimum to ascertain a
best estimate of this cycle's sunspot maximum.

Polar Field Strength

Estimates of the polar magnetic field strength near sunspot
minimum may be obtained from the shape of the corona at the time of
solar eclipses, or by the amount of flattening of the "warped current
sheet" at 1AU as obtained from interplanetary magnetic field measurements
analysed in accordance with the methods of Rosenberg and Coleman (1969).
A further and more direct estimate of polar field strengths is obtained
by observing the number of polar faculae.

The shape of the corona at eclipses may be used to obtain a measure
of polar field strength in the following two ways. The Ludendorf index
(Billings, 1966) may be used as a measure of coronal flattening and hence
of polar field strength. Figure 1a shows the mean sunspot number versus
the Ludendorf index. Each point represents the Ludendorf index
of an eclipse near sunspot minimum (listed) versus the yearly mean
sunspot number at the following solar maximum. The straight
line through the origin is chosen as a best fit to the observations with
the theoretical assumption that if there is a zero polar field at solar
minimum corresponding to a zero Ludendorf index, the next solar maximum
will have few, if any, sunspots. The June 1954 solar eclipse was remarkable
in the flattening of the corona due to the symmetrical plumes over each
pole and the huge equatorial streamers. It was also marked by a very high
amount of solar activity the next cycle, suggestive that these ideas for
predicting solar activity may have some validity.

It should also be noted that some of the scatter of the points
near Ludendorf index 0.23 may be related to the possibility (Svalgaard,
1978) that the interplanetary and coronal fields may have increased
progressively by a factor of two from 1900 to the present time. The
Ludendorf flattening would not reflect an overall change in solar field

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strengths, thus the rise in R_m from 1900 to 1922,
to 1933, and to 1944 along nearly the same flattening index
could be due to an increase in polar field strengths, not reflected in
the flattening index. This can occur because the flattening index only
measures the polar magnetic pressure relative to low latitude field and
plasma pressure. The October 23, 1976 solar eclipse (Waldmeier and Weber,
1977) with a Ludendorf index equal to 0.36 was used to estimate a maximum yearly
mean sunspot number of 155 ± 25, with the uncertainty based upon the spread of
the points near the index 0.23.

A second similar measure of polar field strength and subsequent
solar activity may be obtained from the bending of high latitude polar
plumes. This assumes that a higher polar field strength will bend the
high latitude plumes more toward the solar equator (where
the polar magnetic field pressure is balanced by low latitude field and
coronal plasma pressure). The bending of the polar plumes was obtained
by taking an average of the angle of the coronal plumes from the radial
just above the photosphere at 60° latitude in the four quadrants seen at
solar eclipses. Only those eclipse drawings near solar minimum where
these angles could be determined were used in this study. In Figure 1b,
the bending angle is plotted against the mean sunspot number of the
following maximum. The line shows a best linear fit, again through
the origin, assuming a zero bending angle corresponds to a zero
following sunspot cycle. One can see a relation emerging between polar field
strength (as determined by the bending angle) and the subsequent maximum's
mean sunspot number. The value for the October 23, 1976 eclipse bending
angle was obtained directly from eclipse photos and also from Waldmeier's
(1977) eclipse drawing. These two estimates shown in Figure 1b provide
an estimate for the next maximum's mean yearly sunspot number of 110-140.

The third estimate of polar field strength utilizes the model of
a "warped current sheet" in interplanetary space, whose geometry depends
upon the polar field strength (see Svalgaard and Wilcox, 1976). For a
few years prior to and spanning sunspot minimum the dominant polarity

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of the interplanetary magnetic field as observed at the earth - which through the year is travelling $\pm 7^{\circ}$ out of the solar equatorial plane - shows an annual variation. This is due to the fact that the sector boundary in interplanetary space is very nearly in the east-west direction. This flattening of the current sheet results from strong solar polar fields controlling coronal and interplanetary field configurations. Thus the stronger the flattening the stronger are the polar fields and hence the ensuing sunspot maximum.

The flattening, Δ, may be obtained from interplanetary field measurements near solar minimim by determining the number of days of toward-the-sun field polarity throughout one or more years. The amplitude of this curve, in days, throughout the year (as the earth swings between $\pm 7^{\circ}$ heliographic latitude) is Δ. In Figure 1c, Δ near solar minimum is graphed with the following sunspot maximum yearly mean sunspot number, R_m. The curve is assumed to go through zero as with the previous graphs. The range of Δ near 1976 (shown as arrows) provide an estimate for the next sunspot maximum's mean yearly sunspot number of 135 $\pm$ 20. Again, the ability of the 1964 and 1954 data to fit a line through the origin is seen as supporting the view that subsequent sunspot peaks are related to polar field strengths.

Sheeley (1964,1966,1976) has suggested that the sun's polar field strengths may be estimated by a fourth method - counting the numbers of faculae at the poles. Annual averages of the polar fields from Mt. Wilson synoptic magnetic charts for the years available (1967 through 1975) confirm Sheeley's results. Sheeley also points out that the polar field magnitude tends to lag the sunspot number and that this is consistent with the model that the polar fields are produced by the poleward transport of flux that originates in bipolar magnetic regions in the lower latitude zones of solar activity. In our model, the polar fields near sunspot minimum are the source of the fields to generate the next activity maximum We have compared the sum of north and south polar faculae counts (from Sheeley 1976, Figure 1 but without his polarity determination) with the sunspot number. We found a better correlation between the polar faculae counts

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and the following sunspot maximum than with the preceding one. This supports
the idea that the polar fields near minimum (when the polar fields are
usually the greatest) predict the peak of the following cycle. To attempt
a numerical estimate we have computed 3-year averages of the polar faculae
counts centered about sunspot minimum and plotted them with the maximum
yearly mean sunspot number of the next cycle. Figure 1d shows the result.
The faculae count was a maximum at sunspot minimum for all minima except
1923 and 1954 when it was largest in the declining phase of the cycle.
The faculae count for the 1923 minimum may be biased by an unusually large
count just after the 1917 maximum. As a rough estimate of the coming
maximum we estimate a sunspot number of 120-160 by this method.

Further suggestion of a fairly high sunspot cycle comes from the
work of Brown (1976) who noticed a correlation between solar activity at
solar minimum with the following maximum. Utilizing such a correlation,
with the added fact that this past minimum had the highest ever recorded
value for mean sunspot number (13), suggests the new cycle could have a
mean value of 150 ± 25, near solar maximum.

Prediction of the Sunspot Number of Solar Cycle 21

Utilizing the previous estimate of polar magnetic field strength
obtained near solar minimum, we have four estimates of cycle 21's maximum
mean yearly sunspot number. These are 155 ± 20, 125 ± 20, 135 ± 20, and
140 ± 20. Averaging these two together we get a value of 140 ± 20 for
the mean yearly maximum sunspot number of cycle 21. We have kept the ± 20
uncertainty rather than reducing its value because the four methods are
based on the same physical principles, and any uncertainties in the four
methods may not be independent.

An estimate of the time of rise of the solar activity cycle may be
found from Waldmeier's (1935) formulae, which gives the rise time as 3.4 ± 0.5
years. Placing the solar minimum in April 1976 gives the time of maximum
to be September 1979, to within half a year.

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Figure 2 shows our estimate of sunspot number for cycle 21 as a solid line with dashed lines around it to indicate the limits of our estimate. The mean of cycles 8-20, shown as a dotted line, indicates that we predict cycle 21 to be significantly larger than average.

It is important to add that we are making a prediction of the size of solar cycle 21 using estimates of the polar field strength together with our assumption that this relates to the size of the next cycle's activity. We also believe that more than just this one parameter governs the behavior of the solar activity cycle. We would thus like to think of this paper as a first order attempt to predict the cycle's activity using one parameter of physical importance. If this method succeeds to some degree, it may be possible to establish other solar parameters which will improve the prediction.

The prediction of cycle 21's yearly mean sunspot maximum to be 140 ± 20 is close to Sargent's (1978) prediction of 154 but significantly larger than most other predictions listed in Sargent's paper If we err in the prediction, we feel we have erred on the side of being too conservative. Waldmeier and Weber (1977) point out that this cycle had the largest value of sunspot number at solar minimum ever recorded. Thus it is possible that solar maximum may exceed our stated limits.

Acknowledgements

Figure Captions

Figure 1a (top)   Sunspot number at maximum vs. the Ludendorf isophote
                   flattening index at an eclipse near the preceding solar
                   minimum (used as a measure of polar magnetic strength).

       1b (2nd
          down)   Sunspot number at maximum vs. the polar field bending
                   angle at an eclipse near the preceding solar minimum.

       1c (3rd   Sunspot number at maximum vs. Δ, a measure of the
          down)   yearly variation of the predominant polarity of the
                   interplanetary field near earth. This is used as a
                   measure of polar magnetic field strength.

       1d (bottom) Sunspot number at maximum vs. faculae count in polar
                   regions, and related polar field strength, at the preceding
                   solar minimum.

Figure 2   Predicted smoothed sunspot number from 1976 to 1983
                   (solid curve). A maximum of 140 ± 20 near September,
                   1979 is significantly above the mean of cycles 8-20
                   (dotted curve).

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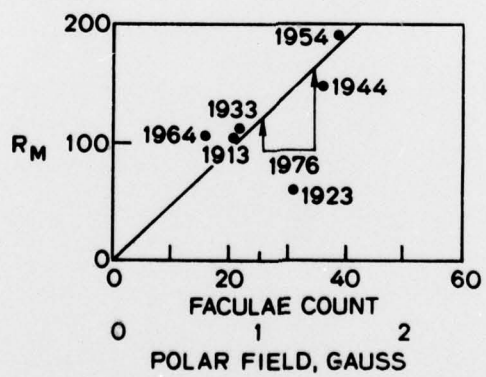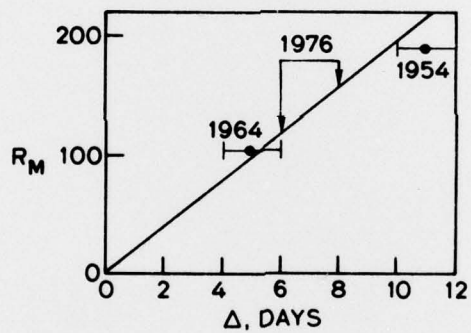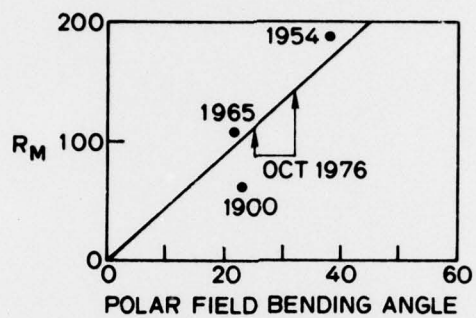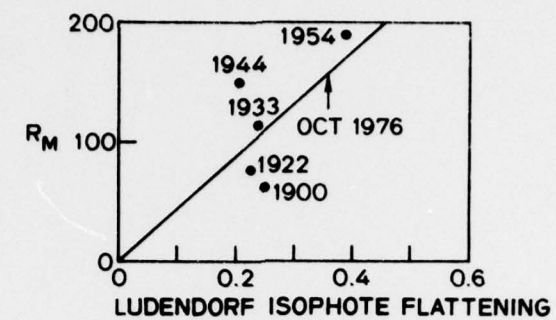   1-24, 1977.

Figure 1

Figure 2